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ABSTRACT

Results are presented of a study examining the Test of Integrated Process Skills (TIPS) and the Tobin and Capie Test of Logical Thinking (TOLT). Each of the two tests was analyzed to provide five subtest and total test scores, which were then correlated to examine relationships between broad measures of process skill and logical thinking ability and facets of each ability. Results include the finding that formal thinking and process skill abilities are highly interrelated. Implications for further research are examined. (CS)

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THE RELATIONSHIP BETWEEN SCIENCE PROCESS SKILL AND FORMAL THINKING ABILITIES

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THE RELATIONSHIP BETWEEN SCIENCE PROCESS SKILL
AND FORMAL THINKING ABILITIES

For some years, science educators (e.g., Gagné, 1965; and Okey, 1972) have argued that acquisition of the science process skills should be a major goal of science instruction. Acceptance of this view is reflected in curricula developed in recent years with an emphasis on the integrated process skills (hypothesizing, identifying and controlling variables, defining operationally, interpreting data, and experimenting). This emphasis is seen in such programs as the Intermediate Science Curriculum Study (1975) and the Biological Sciences Curriculum Study (1973). Developing more recently has been an interest in formal operational thinking abilities (identifying and controlling variables, correlational logic, combinatorial logic, probabilistic logic, and proportional logic) as described by Inhelder and Piaget (1958), and in the relationship between these abilities and science achievement (c.f., Lawson and Block, 1976; Lawson and Nordland, 1977).

A relationship between integrated process skill and formal operational abilities has been hypothesized by several authors (e.g., Padilla, 1979) and seems reasonable. The integrated process skills are involved when conducting experiments; one must formulate a hypothesis, design an experiment, and make generalizations after collecting data. The ability to identify and control variables involves precisely the same steps as in conducting experiments. Other similarities may also exist. For example, experiments in science classes may involve proportional or correlational logic in data interpretation.

However, in the middle and secondary school setting, little research has been done to investigate this relationship, despite strong logical similarities between the two abilities. The purpose of this study was to examine integrated process skill and formal thinking abilities of middle and high school students and determine the relationship, if any, between the two.

RELATED RESEARCH

Lawson, Nordland and DeVito (1975) investigated the interrelationship of several variables with college freshman and sophomore preservice elementary education majors. They found that ability to perform four Piagetian formal operational tasks correlated significantly (r=.37) with achievement on the Wisconsin Inventory of Science Processes (WISP). The WISP, however, does not measure integrated science process skills as defined in this study, but rather is an inventory of knowledge of the scientific enterprise.

Tobin and Capie (1981) found a significant intercorrelation (r=.60) between formal reasoning ability and process skill achievement among middle school students. Students experienced a two-week, integrated process skill unit as a part of their regular science classes. In a multiple regression analysis, formal reasoning ability accounted for 30% of the variability in achievement on both summative and retention process skill tests. The present study seeks to determine the relationship between formal operational abilities and integrated process skills when students have not undergone any special training on science process skills.

PROCEDURE

Two instruments were used to collect the data. The test of Integrated Process Skills (TIPS) provided a measure of their integrated science process skill ability and the Test of Logical Thinking (TOLT) provided scores on the students' logical thinking skills. Each test uses a multiple choice format for responding (with the exception of two items on the TOLT). The instruments had been especially developed to assess integrated process skill and logical thinking ability and had previously been shown to be valid and reliable (Dillashaw and Okey, 1980; Tobin and Capie, 1981).

One middle and one secondary school, from a mixed suburban/rural school district outside Atlanta, Georgia, were chosen for the study. Both schools drew from a predominantly middle class population. Approximately 80 students were selected from each grade level, 7-12 (n=492). Students were carefully chosen to provide the full range of ability levels. Each completed the two measures in a group setting, with tests administered by their teachers on two consecutive days. In grades 7 thru 9 the students were chosen from science classes because all ability levels were represented in these required classes. A sample of both science and non-science classes was chosen in grades 10-12 where science enrollment was by choice. The non-science students were chosen from mandatory English classes.

Each of the two tests was analyzed to provide five subtest and total test scores. The scores (six for each instrument) were correlated to examine relationships between broad measures of process skill and logical thinking ability (total test scores) and facets of each ability

(subtest scores). Both factor analysis and logical analysis support the division of each instrument into subtests. Total test and subtest reliabilities, computed using Cronbach's α, are reported on Table 1. These reliabilities were used to correct all correlations for attenuation.

RESULTS

Table 2 reports the means and standard deviations by grade for both the TIPS and the TOLT total test scores and subtests. The TIPS mean scores gradually increase from 19.68 at grade 7 to 24.56 at grade 12. TOLT mean scores increase from 2.76 at grade 7 to 6.81 at grade 12.

Intercorrelations of all tests and subtests, corrected for attenuation, are reported in Table 3. All correlations are significant ($p<.0001$) with the overall TIPS and TOLT correlation at .73, a relatively high value. Subtests intercorrelate from a moderate .41 to a high of .99; most fall in the .50 to .70 range.

A factor analysis of the scores (promax rotated) was performed which identified one common factor which accounted for 37.4% of the total variation in scores. Each subtest of both the process skill and logical thinking tests correlated from .50 to .71 with the single factor (Table 4).

DISCUSSION

The process skill achievement data (TIPS) in Table 2 show that older students score higher than younger students (as would be expected) except for slightly lower scores for grade 8 students. The process skills mean scores by grade level range from 52% to 68% showing moderate achievement but still substantial room for additional learning. The students in this

study had no particular focused instruction on process skills. The achievement on the process skill subtests is quite uniform at all grade levels--no areas stand out as particularly strong or weak.

The logical thinking data (TOLT) from Table 2 also show progressively higher scores for older students. Average logical thinking scores range from 28% to 68% of the maximum score possible. A person scoring 4 or higher is considered to be a formal operational thinker; on average, students are in this range by grade 10. Substantial numbers of students, however, at all grade levels fail to reach this level of formal thinking. Among the subtests of logical thinking, probabilistic reasoning is relatively low at all grade levels. Proportional logic is initially low but by grade 11 is as high as other modes of logical thinking.

The correlations in Table 3 show a moderate to strong relationship between the process skill and logical thinking abilities. The correlation of .73 between the two total test scores is evidence of a substantial relationship between a student's ability to use science process skills and to think logically.

The factor analysis data corroborates the correlational evidence just described and extends it. The fact that a single factor was identified to which all subtests of logical thinking and process skill tests contribute is strong evidence for a common underlying construct.

IMPLICATIONS

To show that process skill and logical thinking variables are correlated is primarily of academic interest. Of practical interest are cause and effect relationships between the two. Correlational work is the first

step in establishing causal relationships. If two variables are correlated, one may be influencing the other; a follow-up experimental study will determine this.

In the case of process skill and logical thinking abilities, the hope is that logical thinking can be taught--it is one of the most common major goals of schooling. The question is how can logical thinking be taught? This study shows that science process skill ability is strongly associated with logical thinking and is, therefore, a candidate as a factor that has a direct influence on it. The work that remains is to determine in an experimental study if increasing the process skill abilities of students will have an influence on logical thinking.

It is also possible that the direction of the hypothesized relationship between process skill achievement and logical thinking is the reverse of that just described--that is, logical thinking influences process skill abilities. Experimental studies will be needed to determine if alterations in either type of ability (process skill or logical thinking) have an influence on the other.

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Table 1

TOTAL TEST AND SUBTEST RELIABILITIES (CHRONBACH'S α) FOR THE TEST OF INTEGRATED PROCESS SKILLS (TIPS) AND TEST OF LOGICAL THINKING (TOLT)

TIPS		TOLT	
TOTAL	.82	TOTAL	.83
Hypothesizing	.57	Proportional Logic	.77
Identifying Variables	.65	Controlling Variables	.77
Operationally Defining	.42	Probabilistic Logic	.71
Designing Investigations	.22	Correlational Logic	.53
Graphing & Interpreting Data	.45	Combinatorial Logic	.62

Table 2

MEANS AND STANDARD DEVIATIONS OF PROCESS SKILL (TIPS) AND LOGICAL THINKING (TOLT) DATA BY GRADE LEVEL

	GRADE											
	7 N=103		8 N=83		9 N=62		10 N=101		11 N=106		12 N=36	
	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.
TIPS Total (Max=36)	19.68	5.39	18.66	5.98	20.73	6.71	23.31	5.15	24.58	5.49	24.56	7.03
Hypothesizing (Max=9)	4.67	1.67	4.63	1.97	5.37	2.09	5.76	1.68	6.55	1.76	6.47	2.25
Identifying Variables (Max=12)	6.14	2.20	5.33	2.54	6.26	2.69	6.94	2.60	7.33	2.28	7.14	2.67
Operationally Defining (Max=6)	4.28	1.13	4.16	1.29	3.89	1.51	4.63	1.14	4.58	1.17	4.72	1.37
Designing Investigations (Max=3)	1.50	.95	1.64	.83	1.74	.89	2.01	.89	2.08	.79	2.17	.94
Graphing & Interpreting Data (Max=6)	3.10	1.28	2.92	1.35	3.47	1.45	3.96	1.13	4.04	1.28	4.06	1.24
TOLT Total (Max=10)	2.76	2.29	2.88	2.27	3.79	3.05	4.48	3.00	5.70	3.09	6.81	3.22
Proportional Logic (Max=2)	.34	.62	.25	.58	.56	.78	.76	.88	1.25	.87	1.31	.79
Controlling Variables (Max=2)	.60	.77	.63	.79	.69	.86	.99	.92	1.10	.91	1.42	.87
Probabilistic Logic (Max=2)	.33	.62	.43	.72	.65	.83	.81	.85	.92	.89	1.17	.88
Correlational Logic (Max=2)	.82	.80	.73	.77	1.00	.81	.87	.81	1.15	.81	1.42	.81
Combinatorial Logic (Max=2)	.67	.73	.83	.81	.89	1.06	1.04	.85	1.26	.88	1.50	.77

Table 3

INTERCORRELATIONS OF SUBTEST AND TOTAL TEST SCORES OF PROCESS SKILL (TIPS) AND LOGICAL THINKING (TOLT) ABILITIES*

	Proportional Logic	Controlling Variables	Probabilistic Logic	Correlational Logic	Combinatorial Logic	Total
Hypothesizing	.38 (.57)	.39 (.58)	.41 (.65)	.35 (.63)	.28 (.47)	.50 (.73)
Identifying Variables	.35 (.50)	.30 (.43)	.37 (.54)	.35 (.59)	.26 (.41)	.45 (.61)
Operationally Defining	.30 (.53)	.34 (.61)	.32 (.58)	.30 (.64)	.30 (.58)	.44 (.75)
Designing Investigations	.32 (.77)	.27 (.66)	.33 (.84)	.27 (.81)	.32 (.87)	.42 (.99)
Graphing & Interpreting Data	.34 (.58)	.33 (.56)	.39 (.70)	.32 (.67)	.31 (.59)	.47 (.77)
Total	.45 (.56)	.43 (.54)	.48 (.63)	.43 (.65)	.37 (.52)	.60 (.73)

*All correlations are significant ($p<.0001$). Coefficients in parentheses are those corrected for attenuation.

Table 4

INTERCORRELATIONS OF TIPS AND TOLT SUBTESTS WITH THE SINGLE FACTOR DEFINED BY THE PROMAX ROTATED FACTOR ANALYSIS

	Factor 1
Test of Integrated Process Skills	
Hypothesizing	.71
Identifying Variables	.64
Operationally Defining	.59
Designing Investigations	.59
Graphing & Interpreting Data	.65
Test of Logical Thinking	
Proportional Logic	.63
Controlling Variables	.56
Probabilistic Logic	.64
Correlational Logic	.57
Combinatorial Logic	.50